TITLE OF THE INVENTION

OPTICAL DATA RECORDING MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to Japanese application No. 2000-348412 filed on November 15, 2000 whose priority is claimed under 35 USC § 119, the disclosure of which is incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1.Field of the Invention

The present invention relates to an optical data recording medium on which data is recorded and from which data is reproduced, and more particularly, it relates to an optical data recording medium capable of preventing its warp caused by a change in ambient conditions and an elapse of time.

2.Description of Related Art

Fig. 1 is a schematic sectional view illustrating a structure of an optical data recording medium. A conventional optical data recording medium is shown in a plan view and a side view of Figs. 8(a) and 8(b), respectively.

An optical data recording medium comprises, as shown in Fig. 1, a single layered or multilayered thin film layer 40 including at least any one of dielectric films 41, 43 (silicon nitride), a recording film 42 (TbFeCo) and a reflective film 44 (Al) is formed by sputtering or the like on a disc-shaped

substrate 20 made of a polycarbonate. On the thin film layer 40, a protective film 50 such as a resin film for protecting the thin film layer is formed. Further, another protective film 30 such as a resin film for protecting the substrate is formed on a light receiving surface of the substrate.

The substrate 20 is about 1.2 mm thick, the single layered or multilayered thin film layer 40 formed by sputtering is 10-300 nm thick, the protective film 50 is 1-30 μm thick, and the protective film 30 is 1-30 μm thick.

Since the polycarbonate substrate 20 constitutes almost the entire thickness of the optical data recording medium, rigidity of the medium substantially depends on that of the polycarbonate substrate 20. With the sufficient thickness of the polycarbonate substrate 20, deformation of the medium caused by a change in ambient conditions (temperature and humidity) is very small and there is no need to pay attention to a balance between stresses and bending moments generated in the layers.

In recent years, however, data recording and reproducing at high density on and from the optical data recording medium have been required. Accordingly, attempts to increase NA of an objective lens and decrease the substrate thickness have been made for reducing a beam spot diameter.

In general, an effective diameter (γ) of a laser beam incident on a disc-shaped medium is expressed as $\gamma \propto \lambda/NA$

wherein λ is a laser beam wavelength and NA is a numerical aperture of an objective lens. In order to achieve high density recording, the laser beam wavelength λ is reduced and an objective lens with high NA is used. However, by merely increasing the NA, a coma is generated and causes a harmful influence on the recording when the objective lens is slanted with respect to the disc. It is known that the coma increases in proportion to the cube of NA. For preventing the coma, it is necessary to form the substrate with a thickness of $1/(NA)^3$. Accordingly, the thickness of the substrate shows a tendency to decrease from a conventional dimension of 1.2 mm to an almost half or less, i.e., 0.6 mm or 0.5 mm, for realizing the high density recording. In such a case, the rigidity of the optical data recording medium depends upon not only the polycarbonate substrate 20 but also the stresses or bending moments generated in the layers. Such a medium will remarkably be warped if the ambient conditions (temperature and humidity) are changed. Therefore, it is important to establish an appropriate balance between the thicknesses and the like of the layers.

Japanese Unexamined Patent Publication No. Hei 4(1992)-195745 proposes a method of forming a dielectric film on a back surface of the substrate (where the thin film layer is not formed) for preventing the warp.

Fig. 9 shows a sectional view of an optical data

recording medium according to the above publication. Components identical to those shown in Fig. 1 are indicated by the same reference numerals.

As shown in Fig. 9, a dielectric layer 60 is formed on a light receiving surface of a transparent polycarbonate substrate 20. The warp of the optical data recording medium is prevented by equalizing thermal expansion coefficients of a first dielectric film 41, a recording film 42 and a second dielectric layer 43 which are formed on a surface opposite to the light receiving surface of the transparent substrate 20 with the thermal expansion coefficient of the dielectric layer 60 on the light receiving surface of the substrate.

Further, Japanese Unexamined Patent Publication No. Hei 10(1998)-64119 describes that the warp of an optical disc through an increase in temperature is alleviated by applying a thick protective film 50 for protecting the thin film layer. The structure of the optical data recording medium according to the publication is the same as that shown in Fig. 1. According to the publication, the thin film layer 40 is formed on the polycarbonate substrate 20 and then the protective film 50 of about 30-50 μm thick is formed to protect the thin film layer 40. With the thick protective film 50, the thermal expansion of the polycarbonate substrate 20 and that of the protective film 50 are balanced to reduce the warp of the disc.

Fig. 10 shows a section of another conventional

optical data recording medium according to Japanese Unexamined Patent Publication No. Hei 4(1992)-364248.

The recording medium comprises a substrate 20, a thin film layer 40, a protective film 50 for protecting the thin film layer and a protective film 30 (a dielectric layer) for protecting the substrate. For preventing the warp caused by a change in humidity, an anti-permeation film 70 made of SiO_2 or AlN is formed between the substrate 20 and the protective film 30.

In both of the above-mentioned conventional recording media according to Japanese Unexamined Patent Publications Nos. Hei 4(1992)-195745 and 4(1992)-364248, the dielectric layer (30, 60) must be formed by sputtering or the like on the light receiving surface of the substrate. Accordingly, in the manufacture thereof, the thin film layer 40 is formed on a surface of the substrate and then the substrate is turned over to form the dielectric layer (60, 30) on an opposite surface. Therefore, the manufacture is complicated and the charge of the manufacture facility is raised, which increases the manufacture cost.

Further, according to the method of Japanese Unexamined Patent Publication No. Hei 10(1998)-64119, the thickness of the protective film 50 becomes too great, which increases the costs and complicates the process.

Where the optical data recording medium is a

magneto-optic data recording medium, it is desirable to bring a magnetic head coil adjacent to the thin film layer 40 in order to reduce the magnetic field and inductance of the magnetic head coil to reverse a magnetic field at high speed during data recording. Therefore, the thick protective film 50 results in the reduction of magnetic properties of the magneto-optic data recording medium and causes problems in the data recording/reproducing.

SUMMARY OF THE INVENTION

The present invention is an optical data recording medium which is easily manufactured and capable of preventing the deformation (warp) caused by a change in temperature and humidity.

The present invention provides an optical data recording medium comprising a transparent substrate, a thin film layer formed on the transparent substrate and a protective film which is mainly comprised of a resin and formed on the thin film layer for protecting the thin film layer, wherein the thin film layer is a single layered or multilayered film including at least any one of a dielectric film, a recording film and a reflective film, and at least either one of a linear expansion coefficient and a Young's modulus of the protective film is greater than that of the transparent substrate, the linear expansion coefficient of the protective film being greater than 7.0×10^{-5} (1/℃) and smaller than 5.0×10^{-4} (1/℃).

These and other objects of the present application will become more readily apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic sectional view illustrating a structure of an optical data recording medium;

Fig. 2 is a view illustrating how the optical data recording medium is warped;

Fig. 3 is a view illustrating a multilayered beam;

Fig. 4 is a graph illustrating a time dependency of a warp angle of a conventional medium through a change in temperature (indicating a low linear expansion coefficient);

Fig. 5 is a graph illustrating a time dependency of a warp angle of a medium according to Example 1 of the present invention through a change in temperature (indicating a high linear expansion coefficient);

Fig. 6 is a graph illustrating a time dependency of a warp angle of a medium according to Example 2 of the present invention through a change in temperature (indicating a high

Young's modulus);

Fig. 7 is a graph illustrating a relationship between a linear expansion coefficient and a Young's modulus of the medium according to Example 1;

Figs. 8(a) and 8(b) are a plan view and a side view each illustrating a structure of a conventional optical data recording medium;

Fig. 9 is a schematic sectional view illustrating a conventional optical data recording medium;

Fig. 10 is a schematic sectional view illustrating another conventional optical data recording medium;

Fig. 11 is a table illustrating settings of components of the medium according to Example 1 of the present invention;

Fig. 12 is a table illustrating settings of components of the conventional medium; and

Fig. 13 is a table illustrating settings of components of the medium according to Example 2 of the present invention.

Fig. 14 is a graph illustrating a time dependency of a warp angle of a medium according to Example 3 of the present invention through a change in temperature.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides an optical data recording medium comprising a transparent substrate, a thin film layer formed on the transparent substrate and a protective film which is mainly comprised of a resin and formed on the

thin film layer for protecting the thin film layer, wherein the thin film layer is a single layered or multilayered film including at least any one of a dielectric film, a recording film and a reflective film, and at least either one of a linear expansion coefficient or a Young's modulus of the protective film is greater than that of the transparent substrate, the linear expansion coefficient of the protective film being greater than 7.0×10^{-5} (1/℃) and smaller than 5.0×10^{-4} (1/℃).

According to the present invention, the deformation (warp) of the medium itself is prevented to such a degree that substantial influences are not caused to the data recording and reproducing, which improves reliability of the medium through data recording/reproducing as compared with the prior art media.

According to the present invention, it is necessary that the relationship between the protective film for protecting the thin film layer and the transparent substrate satisfies any one of the following conditions:

(a) linear expansion coefficient of the protective film > linear expansion coefficient of the transparent substrate;

(b) Young's modulus of the protective film > Young's modulus of the transparent substrate; and

(c) linear expansion coefficient of the protective film > linear expansion coefficient of the transparent substrate and Young's modulus of the protective film > Young's modulus of the

transparent substrate.

In any cases of the above (a), (b) and (c), the linear expansion coefficient of the protective film needs to be in the range of 7.0×10^{-5} (1/℃) and 5.0×10^{-4} (1/℃) in view of preventing the warp.

The present invention further provides an optical data recording medium comprising a transparent substrate, a thin film layer formed on the transparent substrate and a protective film which is mainly comprised of a resin and formed on the thin film layer for protecting the thin film layer, wherein the thin film layer is a single layered or multilayered film including at least any one of a dielectric film, a recording film and a reflective film, and at least either one of a linear expansion coefficient and a Young's modulus of the protective film is greater than that of the transparent substrate, the Young's modulus of the protective film being greater than 2.0×10^{9}(Pa) and smaller than 1.0×10^{10}(Pa).

Also in this case, any one of the above-mentioned conditions (a), (b) and (c) needs to be satisfied and the Young's modulus needs to be in the above-mentioned range.

Here, the protective film 50 for protecting the thin film layer has a thickness of 5 μm or more to 20 μm or less. The transparent substrate may be made of a polycarbonate or a polyolefin.

In order to effectively prevent the warp of the medium,

the protective film for protecting the thin film layer is made of a material satisfying the above-mentioned linear expansion coefficient and Young's modulus. Examples of such a material include an ultraviolet light curing resin mainly comprised of polyester acrylate, epoxy acrylate, urethane acrylate, or polyether acrylate.

The optical data recording medium according to the present invention does not require a protective film 30 for protecting the substrate as provided in the conventional media. However, for preventing the scratches and inhibiting the warp, the protective film 30 for protecting the substrate may be formed on a light receiving surface of the transparent substrate 20, though the total thickness of the medium somewhat increases.

Further, the present invention further provides a method of selecting a protective film in an optical data recording medium, the optical data recording medium comprising a transparent substrate, a thin film layer formed on the transparent substrate and the protective film which is mainly comprised of a resin and formed on the thin film layer for protecting the thin film layer, wherein, on condition that the thin film layer is a single layered or multilayered film including at least any one of a dielectric film, a recording film and a reflective film and the transparent substrate is made of a polycarbonate or a polyolefin with a thickness of 0.5 mm, the

protective film is selected such that at least either one of a linear expansion coefficient and a Young's modulus of the protective film is greater than that of the transparent substrate and the linear expansion coefficient of the protective film is greater than 7.0×10^{-5} (1/℃) and smaller than 5.0×10^{-4} (1/℃).

Still further, the present invention provides a method of selecting a protective film in an optical data recording medium, the optical data recording medium comprising a transparent substrate, a thin film layer formed on the transparent substrate and the protective film which is mainly comprised of a resin and formed on the thin film layer for protecting the thin film layer, wherein, on condition that the thin film layer is a single layered or multilayered film including at least any one of a dielectric film, a recording film and a reflective film and the transparent substrate is made of a polycarbonate or a polyolefin with a thickness of 0.5 mm, the protective film is selected such that at least either one of a linear expansion coefficient and a Young's modulus of the protective film is greater than that of the transparent substrate and the Young's modulus of the protective film is greater than 2.0×10^{9}(Pa) and smaller than 1.0×10^{10}(Pa).

First, the deformation (warp) of the optical data recording medium through a change in temperature and its principle will be described.

The optical data recording medium intended by the

present invention is comprised of, for example, a transparent substrate 20 made of a polycarbonate and a single layered or multilayered thin film layer 40 including dielectric films 41, 43 (aluminum nitride, silicon nitride), a recording film 42 (TbFeCo) and a reflective film 44 (Al alloy) formed on the substrate by sputtering. On the thin film layer 40 a protective film 50 mainly comprised of a resin is formed to protect the thin film layer 40. Further, a protective film 30 mainly comprised of a resin is formed on a light receiving surface of the substrate to protect the substrate.

Various media with the above-mentioned structure have been commercialized. Objects of the present invention includes: magneto-optical recording media such as MD and MO; media for reproduction only such as CD, DVD and DVD-ROM in which the thin film layer 40 includes the reflective film 44 (Al or the like) only; write-at-once optical media such as CD-R and DVD-R in which the thin film layer 40 includes an organic pigment film and the reflective film 44 (Au, Ag); and phase change optical recording media such as CD-RW, DVD-RW, DVD-RAM and DVR in which the thin film layer 40 includes the dielectric films 41, 43 ($ZnS\text{-}SiO_2$ or the like), the recording film 42 (GeSbTe, AgInSb or the like) and the reflective film 44 (Al alloy or the like).

The optical data recording medium is formed of multiple layers as described above. The layers are different in

physical property such as a linear expansion coefficient and so in stress generated in the layers by a change in temperature.

In general, the transparent polycarbonate substrate 20, the protective film 30 for protecting the substrate and the protective film 50 for protecting the thin film layer each show the linear expansion coefficient greater than that of the single layered or multilayered thin film layer 40. Accordingly, the expansion of the single layered or multilayered thin film layer 40 in a direction of a substrate radius is much smaller than that of the other layers.

In such a case, a thickness of the transparent substrate 20 is much greater than that of the protective film 30 and that of the protective film 50. Further, films comprising the thin film layer 40 each show a Young's modulus extremely greater than that of the other layers. Accordingly, the deformation caused by a change in temperature is predominantly derived from the small expansion of the thin film layer 40 and the great expansion of the substrate 20. As a result thereof, the optical data recording medium 10 is easily warped in a direction perpendicular to its radius direction, i.e., a direction of its thickness, towards the protective film 30 for protecting the substrate.

Fig. 2(a) is a plan view and Fig. 2(b) is a side view of the medium illustrating the warp of the medium. The direction of the warp of the medium toward the protective film

50 for protecting the thin film layer as indicated by the broken line is defined as a plus (+) direction and the direction toward the protective film 30 for protecting the substrate (the light receiving surface) is defined as a minus (-) direction as indicated by a broken line in Fig. 2(b).

Where the linear expansion coefficient, Young's modulus and thickness of the protective film 50 are suitably adjusted, bending moments of the transparent substrate 20 and the protective film 30 for protecting the substrate generated by a change in temperature are balanced with that of the protective film 50 with respect to a neutral plane, i.e., a plane perpendicular to the film thickness direction. Accordingly, the deformation caused by the temperature change, i.e., the warp in the film thickness direction perpendicular to the radius direction toward the protective film 30, may possibly be alleviated.

In view of the above and for the purpose of reducing the warp of the medium through the temperature change, the following rough calculation is carried out to obtain appropriate values of the linear expansion coefficient, Young's modulus and thickness of the protective film 50 for protecting the thin film layer.

When the temperature is changed, stresses are generated in a radius direction (axial force), a circumference direction and a film thickness direction in the optical data

recording medium 10. Since the medium 10 is disc-shaped, the stress in the circumference direction is uniform in the circumference. Further, the stress in the film thickness direction is also applied uniformly in each layer. Accordingly, it is assumed that these stresses do not contribute to the deformation. Therefore, it is considered that the deformation, i.e., the warp of the medium 10 (in the film thickness direction perpendicular to the radius direction toward the protective film 30 (- direction); evaluated by a warp angle θ), is substituted with a warp of a multilayered beam having a section corresponding to that of the medium. Fig. 3 shows such a multilayered beam.

The multilayered beam of Fig. 3 includes n layers. The n signifies the number of layers comprising the optical data recording medium. In the medium shown in Fig. 1, n is 7.

The warp angle θ in the multilayered beam through a change in temperature is expressed by the formulae (1) to (5) obtained from the balance between axial force Pi (i = 1, 2, 3, ..., n) and bending moment Mi in each layer ("Electronic Devices Utilizing Multilayered Beam Theory" Juhachi ODA, Kanazawa Univ., Japan Machine Academy Papers, vol. 59, 563, 1777-1782 pp., 1993).

$$Mi = \frac{Ei\ Ii}{Ri} \quad \cdots\cdots\cdots(1)$$

$$\alpha_i T + \frac{Pi}{b\ ti\ Ei} - \frac{ti}{2Ri} = \alpha_{i+1} T + \frac{P_{i+1}}{b\ t_{i+1} E_{i+1}} + \frac{t_{i+1}}{2R_{i+1}} \quad \cdots\cdots\cdots(2)$$

$$\sum_{i=1}^{n} Pi = 0 \quad \cdots\cdots\cdots(3)$$

$$\sum_{i=1}^{n} Mi + P_1\left[y - \frac{t_1}{2}\right] + P_2\left[y - t_1 - \frac{t_2}{2}\right] + \cdots + P_n\left[y - t_1 - t_2 - \cdots - \frac{t_n}{2}\right] = 0 \quad \cdots\cdots\cdots(4)$$

$$\theta = \tan^{-1}\left[\frac{L-2}{R}\right] \quad \cdots\cdots\cdots(5)$$

Symbols in the formulae (1)-(5) have the following meanings:

α_i: linear expansion coefficient of an i-layer;

E_i: Young's modulus of the i-layer;

t_i: thickness of the i-layer;

P_i: axial force in the i-layer;

M_i: bending moment in the i-layer;

R_i: radius of curvature in the i-layer;

I_i: secondary moment of section of the i-layer;

b: beam width (defined as a unit length);

T: amount of temperature change(℃);

L: beam length;

y: position of a neutral plane in the n layered beam; and

θ: warp angle at a beam length of 4 mm where the maximum

warp is caused.

Since the thickness of each layer is much smaller than the radius of curvature, it is assumed that all the layers (i = 1, 2, ..., n) have the same radius of curvature ($R_1 = R_2 = R_3 = \ldots R_n = R$). The amount of temperature change T signifies a temperature of the medium itself under the ambient temperature (−15 to 80℃ in general).

In order to control the warp of the medium caused by a change in temperature, the Young's modulus, linear expansion coefficient and thickness of the protective film 50 for protecting the thin film layer are selected by using the above formulae (1)-(5) such that the warp angle θ is reduced. That is, these formulae allow selecting the Young's modulus and the like to arrange the position of the neutral plane (y) within the thin film layer during the temperature change. Moreover, it is expected that the deformation of the thin film layer 40 showing the lowest deformation speed among the layers in the medium becomes very small, and the overshooting of displacement, which causes problems through an actual change in temperature, is also reduced. Further, where the Young's modulus and the linear expansion coefficient of the protective film 50 are set greater than those of the substrate 20 by using the formulae (1)-(5), the position of the neutral plane (y) is arranged within the thin film layer 40 such as a recording film even if the protective film 50 is thin, which

allows prevention of the warp.

Optical data recording media manufactured according to the above principle will be described by way of examples. Here, the thin film layer 40 is a single layer of aluminum nitride. In most cases the deformation of the thin film layer 40 is derived from a dielectric layer of aluminum or the like, so that it is possible to consider that the thin film layer 40 comprised of multilayers will show the deformation similar to that of the single layered thin film layer. The optical data recording media in the examples do not include the film 30 for protecting the substrate. If the protective film 30 is provided, thicknesses of the other layers (in particular the protective film 50 for protecting the thin film layer) must be determined appropriately in view of the presence of the protective film 30.

Example 1

On a polycarbonate substrate (the transparent substrate 20) an aluminum nitride thin film layer (the thin film layer 40) and an ultraviolet light (UV) curing resin 1 (the protective film 50 for protecting the thin film layer) which is designed on the basis of the formulae (1)-(5) are formed to provide an optical data recording medium of Example 1. Further, an optical data recording medium of Comparative Example 1 is provided by forming a thin film layer of aluminum nitride and a conventional UV curing resin 2 (the protective film 50) on a polycarbonate substrate. Figs. 11 and 12

describe the structures of the medium according to Example 1 and Comparative Example 1, respectively.

As seen in Figs. 11 and 12, the two optical data recording media are different in linear expansion coefficient of the UV curing resin used as the protective film 50 for protecting the thin film layer. The optical data recording medium of Example 1 specified in Fig. 11 has the greater linear expansion coefficient than that of the comparative medium. In both media, the transparent substrate 20 has an internal diameter of 8 mm, an external diameter of 50 mm and a thickness of 0.5 mm.

In the optical data recording medium according to the present invention, selected is a protective film 50 for protecting the thin film layer having a linear expansion coefficient of 9.50×10^{-5} which is greater than that of the conventional UV curing resin 2 and a thickness of 16 μm which is determined by the formulae (1)-(5). For comparison with the conventional optical data recording medium specified in Fig. 12, the two media are subjected to a change in ambient conditions such that the temperature increases from 25℃ to 70℃. Thus, variation of the warp angle θ (Δθ) at the circumference (r=24mm) through an elapse of time is measured.

Figs. 4 and 5 each show a graph illustrating a relationship between the variation of the warp angle (tilt with respect to the radius direction: mrad) and time (hour) through

a change in relative temperature. Fig. 4 shows the graph of the conventional optical data recording medium of Fig. 12 and Fig. 5 shows the graph of the optical data recording medium according to Example 1 of the present invention of Fig. 11.

The warp angle variation in a plus quantity indicates that the medium is warped toward the protective film 50, and the warp angle variation in a minus quantity indicates that the medium is warped toward the opposite direction, i.e., the protective film 30 (light receiving surface).

According to Figs. 4 and 5, the conventional medium and the medium of the invention show the linear expansion coefficient of 5.62×10^{-5} (1/℃) and 9.50×10^{-5} (1/℃), respectively.

That is, Fig. 4 indicates that the protective film 50 in the conventional medium exhibits a low linear expansion coefficient, whereas Fig. 5 indicates that the protective film 50 in the medium according to Example 1 exhibits a high linear expansion coefficient.

Referring to Fig. 4, the warp angle is varied to about +10 mrad when the ambient temperature is increased to 70℃, which indicates that the conventional medium is greatly warped toward the protective film 50.

In contrast, referring to Fig. 5, the warp angle is varied to about +2 mrad or less even if the ambient temperature is raised to 70℃, which indicates that the medium

according to Example 1 is slightly warped toward the protective film 50.

According to the optical data recording medium of the present invention, the variation of the warp angle is very small as compared with the medium of Comparative Example 1 even if the temperature is changed in the same manner. That is, in the medium of the present invention, the deformation is inhibited even if the thickness of the protective film 50 is 20 μm or less.

Fig. 7 shows a graph illustrating a relationship between the linear expansion coefficient and the Young's modulus of the optical data recording medium according to Example 1 of the present invention specified in Fig. 11. In Fig. 7, curve a1 is derived from a medium with the protective film 50 of 20 μm thick and the warp angle variation of –5 mrad, curve a2 is derived from a medium with the protective film 50 of 20 μm thick and the warp angle variation of +5 mrad, curve b1 is derived from a medium with the protective film 50 of 5 μm thick and the warp angle variation of –5 mrad and curve b2 is derived from a medium with the protective film 50 of 5 μm thick and the warp angle variation of +5 mrad.

Where the thickness of the protective film 50 is in the range of 5-20 μm, the relationship between the linear expansion coefficient and the Young's modulus is plotted between the curves a2 and b1. In order to settle the variation

of the warp angle within the range of ± 5 mrad, the linear expansion coefficient and the Young's modulus need to be adjusted appropriately such that the relationship therebetween is plotted between the curves a1 and a2 when the thickness of the protective film 50 is 20 μm, or between the curves b1 and b2 when the thickness of the protective film 50 is 5 μm.

Suppose that the Young's modulus is fixed to 2.0×10^{9} (Pa) and the thickness of the protective film 50 is 20 μm, the linear expansion coefficient of the protective film 50 is preferably greater than that of the transparent substrate and within the range of about 1.2×10^{-4} (1/℃) to 2.0×10^{-4} (1/℃). Where thickness of the protective film 50 is changed to 5 μm, the linear expansion coefficient of the protective film 50 is preferably greater than that of the transparent substrate and within the range of about 3.2×10^{-4} (1/℃) to 4.9×10^{-4} (1/℃).

According to the graph, where the protective film 50 has the thickness in the range of 5-20 μm, the linear expansion coefficient thereof is preferably greater than that of the transparent substrate, greater than 7.0×10^{-5} (1/℃) and smaller than 5.0×10^{-4} (1/℃) in order to settle the warp angle variation within the range of ± 5 mrad. More preferably, the linear expansion coefficient is greater than 1.0×10^{-4} (1/℃) and smaller than 2.0×10^{-4} (1/℃), i.e., within the range of 1.5 to 3 times as great as that of the transparent substrate 20 (6×10^{-5} (1/℃)).

As described above, the protective film 50 for protecting the thin film layer is selected to have the linear expansion coefficient within the appropriate range. Therefore, the warp of the optical data recording medium is controlled within the appropriate range where substantial influences are not caused to the data recording and reproducing.

Example 2

Hereinafter, explanation is given to an optical data recording medium utilizing a UV curing resin 3 exhibiting a high Young's modulus. Fig. 13 shows the structures of the medium according to Example 2.

Comparing the medium of Example 2 specified in Fig. 13 and the medium of Comparative Example 1 specified in Fig. 12, they are different in material of the UV curing resin 3 comprising the protective film 50 for protecting the thin film layer. Further, the Young's modulus of the medium of Example 2 (9.00×10^9 (Pa)) is greater than that of the medium of Comparative Example 1. That is, the protective film 50 in the medium of Example 2 exhibits a high Young's modulus.

Fig. 6 shows a graph illustrating a relationship between the variation of the warp angle (mrad) and time (hour) through a change in temperature.

In the same manner as in Example 1, the two media are subjected to a change in ambient conditions such that the temperature increases from 25℃ to 70℃. Then, the graph is

formed by measuring the variation of the warp angle θ (Δθ) at the circumference (r=24mm) through an elapse of time.

Fig. 6 shows that the warp angle is varied to about +6.5 mrad when the temperature is raised to 70℃, i.e., the medium is warped toward the protective film 50. However, the warp is smaller than that caused in the conventional medium shown in Fig. 4.

Further, the graph of Fig. 7 illustrating the relationship between the linear expansion coefficient and the Young's modulus indicates that, in order to control the warp angle to 5 mrad or less in the case where the protective film 50 is 5-20 μm thick, it is necessary for the protective film 50 to have the Young's modulus at least greater than that of the transparent substrate, greater than 2.0×10^9 (Pa) and smaller than 1.0×10^{10} (Pa). More preferably, the protective film 50 has the Young's modulus in the range of 3.0×10^9 (Pa) to 6.0×10^9 (Pa).

Example 3

Example 3 relates to an optical data recording medium of the present invention under the conditions wherein not only the temperature but also humidity is changed.

In general, the medium is deformed under the temperature change, as well as under the humidity change. Accordingly, the material of the protective film for protecting the thin film layer may be selected in view of not only the

linear expansion coefficient which varies depending on the change in temperature but also an expansion coefficient under humidity which varies depending on the change in humidity.

While the linear expansion coefficient is determined as a parameter of the deformation of the substrate depending on the temperature, the expansion coefficient under humidity is determined as a parameter of the deformation of the substrate depending on the humidity. That is, the expansion coefficient under humidity of the protective film for the thin film layer is determined as a ratio of expansion thereof (1/%) when a difference of relative humidity (vapor content/saturated vapor amount at 25℃) is increased by 1%.

It is described above that the five formulae are used to select the linear expansion coefficient of the protective film 50 to control the warp angle θ. The same formulae can be used to select the suitable range of the expansion coefficient under humidity. That is, the above formulae (1)-(5) are used to select the expansion coefficient under humidity by replacing the linear expansion coefficient α_i and the amount of temperature change T with the expansion coefficient under humidity and the amount of humidity change (%), respectively.

As described above, the Young's modulus of the protective film 50 is preferably greater than that of the transparent substrate, greater than 2.0×10^9 (Pa) and smaller than 1.0×10^{10} (Pa). In view of this suitable range of the

Young's modulus, the expansion coefficient under humidity is preferably greater than that of the transparent substrate and smaller than 1.7×10^{-4} (1/%).

Considering the three deformation parameters of the linear expansion coefficient, the expansion coefficient under humidity and the Young's modulus, it is preferable that the protective film 50 is selected such that all the conditions (a) to (f) below are satisfied:

(a) linear expansion coefficient of the protective film 50 > linear expansion coefficient of the transparent substrate 20;

(b) expansion coefficient under humidity of the protective film 50 > expansion coefficient under humidity of the transparent substrate 20;

(c) Young's modulus of the protective film 50 > Young's modulus of the transparent substrate 20;

(d) 7.0×10^{-5} < linear expansion coefficient of the protective film 50 < 5.0×10^{-4} (1/℃);

(e) 0 <expansion coefficient under humidity of the protective film 50 < 1.7×10^{-4} (1/%); and

(f) 2.0×10^{9} <Young's modulus of the protective film 50 < 1.0×10^{10} (Pa)

For example, the protective film 50 for protecting the thin film layer (UV curing resin) is selected to have the linear expansion coefficient of 9.5×10^{-5} (1/℃), the expansion coefficient under humidity of 1.6×10^{-5} (1/%) and the Young's

modulus of 5.4×10^9 (Pa). The optical data recording medium using the thus selected protective film shows the variation of the warp angle in the range of +0.7 mrad to −1.6 mrad under the temperature changing from 25℃ to 70℃ and the humidity changing from 50% to 90% as shown in Fig. 14. At this time, the transparent substrate 20 has the linear expansion coefficient of 6.0×10^{-5} (1/℃), the expansion coefficient under humidity of 7.0×10^{-6} (1/%) and the Young's modulus of 2.41×10^9 (Pa). The transparent substrate 20 is 0.5 mm thick and the protective film 50 is 16 μm thick.

Also in this case, the warp of the medium falls within the range of ±5 mrad as in the above Examples, which controls the warp of the medium within such a range that substantial influences are not caused to the data recording and reproducing.

According to the present invention, the optical data recording medium is provided with the protective film for protecting the thin film layer having the linear expansion coefficient which is greater than that of the transparent substrate and falls within a desired range. Therefore, even if the protective film is formed to have a thickness as small as about 5-20 μm, the warp of the medium is controlled more effectively than in the conventional medium to such a degree that substantial influences are not caused to the data recording and reproducing, which improves reliability in the

data recording and reproducing.

Further, since the optical data recording medium is provided with the protective film for protecting the thin film layer having the Young's modulus greater than that of the transparent substrate and falls within a range as great as possible, the warp of the medium is reduced as compared with the conventional medium such that substantial influences are not caused to the data recording and reproducing, which improves reliability in the data recording and reproducing.

In the case where the protective film for protecting the substrate is not provided, the optical data recording medium capable of reducing the warp caused by the change in temperature can be manufactured with smaller costs and the reliability of the medium through the repetitive data recording/reproducing is improved.